

Two New Species of *Quadrastichus* Girault (Hymenoptera: Eulophidae): Parasitoids of the Leafminers *Phyllocnistis citrella* Stainton (Lepidoptera: Gracillariidae) and *Liriomyza trifolii* (Burgess) (Diptera: Agromyzidae)

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Abstract.—The parasitoids *Quadrastichus citrella* Reina and La Salle and *Q. plaquoi* Reina and La Salle (Hymenoptera: Eulophidae) are described. *Quadrastichus citrella*, native of South-East Asia, has been used as a biological control agent of the citrus leafminer *Phyllocnistis citrella* Stainton (Lepidoptera: Gracillariidae) in several countries that the pest has recently invaded. *Quadrastichus plaquoi*, from India, is a parasitoid of *Liriomyza trifolii* (Burgess) (Diptera: Agromyzidae). Characters of these new species are discussed, as well as their relationship to other members of the “*anysis* group” of species. Distributional and biological details of these wasps are given.

Leafmining insects can be severe pests that reduce plant metabolic activities and can lead to desiccation, and premature fall of the leaves. If leaves are seriously attacked, crops can be reduced or seedling plants even totally destroyed (Spencer 1990). The leafmining habit is found in several species of Lepidoptera and Diptera and also in some Coleoptera and Hymenoptera. The main antagonists of leafminers are parasitic Hymenoptera, especially those belonging to Chalcidoidea, which penetrate the mines with their ovipositors to lay eggs in or on the body of the mining larvae or to feed on the host's body fluids (Askew and Shaw 1974).

Among Lepidoptera, the citrus leafminer (CLM) *Phyllocnistis citrella* Stainton (Gracillariidae) is an important pest which has recently spread throughout all citrus areas around the world. This species, native of South-East Asia, entered Africa and Australia in the early 1900's and has spread throughout the Mediterranean Basin and in the New World from SE and

SW USA to South America in the last decade (Hoy and Nguyen 1997, Gates et al. 2002).

In newly infested citrus-growing regions, the CLM indigenous antagonists (mainly parasitoids) have never been able to reduce damage below economic threshold, as reported from Florida (Hoy and Nguyen 1997), Israel (Argov and Rössler 1996), Italy (Siscaro et al. 2003), Spain (Garrido Vivas 1995) and Turkey (Uygun et al. 1996). However in the native range, pest population can be controlled below the economic threshold by natural enemies, which represent its main biological mortality factor (Morakote and Nanta 1996, Tan and Huang 1996, Wang et al. 1999). Therefore, in order to achieve natural control of this pest, several parasitoids have been introduced to the newly infested countries from the native range of *P. citrella*. Among these, *Quadrastichus citrella* sp.n. (Hymenoptera: Eulophidae) has been used in Cyprus, Israel, Italy, Morocco and Spain (as *Q.* sp. “A” in Schauff

et al. 1998; as *Q. sp.* in Smaili et al. 1999, Argov 2000, Barbagallo et al. 2000). However, the only evidence of establishment for this species is in Spain, where the species overwintered in the Valencia area (García Marí et al. 2000).

Among Diptera, agromyzid leafminers, and particularly the species belonging to the genus *Liriomyza* Mik, are considered damaging pests of numerous vegetable and floricultural crops throughout the world. Several of these species can cause extensive economic damage to a large range of host plants under both field and greenhouse conditions (Spencer 1989). Knowledge about agromyzid natural enemies has become increasingly important as a key element to biological control strategies of these pests. A large number of parasitoids have been recorded in the New and Old World, especially species from the families Eulophidae and Pteromalidae (Chalcidoidea) and, less commonly, species of the families Braconidae (Ichneumonoidea) and Eucoilidae (Cynipoidea) (Konishi 1998, Murphy and La Salle 1999). Nevertheless, the majority of these species are generalists and care must be taken when deciding to introduce exotic natural enemies. Biological control strategies appropriate for agromyzid leafminers in field vegetables often include the introduction of appropriate exotic natural enemies or conservation and enhancement of local natural enemies. However, these strategies are not mutually exclusive, as it is clear that any introductions should take into account the existing local natural enemy community (La Salle 1993, La Salle and Gauld 1993). Recently, Murphy and La Salle (1999) recommended that, due to the prevalence and often general nature of leafminer parasitoids, effort should be put into understanding and conserving indigenous leafminer parasitoids rather than relying solely on the introduction of exotic parasitoids. *Quadrastichus plaquoi* sp.n. found parasitising *L. trifolii* (Burgess) in India is an example of a species which

might be used in future sustainable control programs.

Species of *Quadrastichus* are often endoparasites of Cecidomyiidae (Diptera); less commonly, they parasitize Cynipidae (Hymenoptera), Buprestidae and Curculionidae (Coleoptera), Agromyzidae and Tephritidae (Diptera). Also, *Q. saji* (Szelenyi) larvae are predatory of eriophid mites within galls (Graham 1991, La Salle 1994, Hansson and La Salle 1996).

Within the Tetrastichinae, *Quadrastichus* is characterized by having the following characters: a single seta on submarginal vein; mesoscutum usually with a single adnotaular seta; propodeum without Y-shaped paraspicular carina; cercal setae unequal in length, with one being distinctly longer and sinuate; antenna with all funicular segments longer than wide; scutellum with submedian and sublateral lines; propodeal spiracles close or fairly close to metanotum, with their rim exposed; ovipositor sheaths not or only slightly projecting beyond last tergite of gaster (Graham 1991).

This genus was treated under the name *Cecidotetrastichus* Kostjukov (Kostjukov 1977, Graham 1987), but Boucek (1988: 677) remarked on the similarity between *Quadrastichus* and *Cecidotetrastichus* and Graham and La Salle (1991) placed *Cecidotetrastichus* in synonymy with *Quadrastichus*. Discussions on differentiating *Quadrastichus* from related genera, such as *Aprostocetus* Westwood, *Citrostichus* Boucek, *Oomyzus* Rondani and *Tetrastichus* Haliday in particular, are available in literature (Graham 1987, 1991, La Salle 1994, Schauf et al. 1998, Reina and La Salle 2003). At the moment, keys to *Quadrastichus* species are available only for Europe (Graham 1991).

ABBREVIATIONS

ANIC, Australian National Insect Collection, CSIRO Entomology, Canberra, Australia; **BMNH**, The Natural History Museum, London, UK; **DISTEF**, Diparti-

mento di Scienze e Tecnologie Fitosanitarie, University of Catania, Italy; **EMBT**, Department of Agriculture, Bangkok, Thailand; **INPC**, National Pusa Collections, Indian Agriculture Research Institute, New Delhi, Haryana, India; **IZCAS**, Institute of Zoology, Chinese Academy of Sciences, Beijing, China; **USNM**, National Museum of Natural History, Washington D.C., USA.

Quadrastichus citrella Reina and La Salle, sp. nov.

(Figs. 1, 2, 4–11, 14, 15)

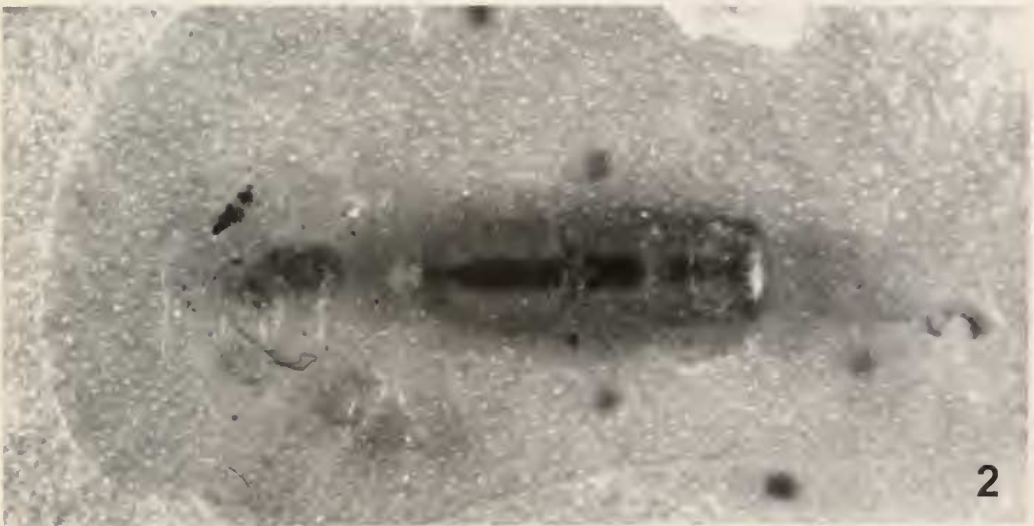
Diagnosis.—Body mainly yellowish with metanotum brown, transverse dark band on 3–4th gastral segments. Frons with broad median area rather than distinct median line. Malar sulcus curved, without fovea beneath eye. Antennal scape not reaching above top of vertex. First funicular segment slightly shorter than other two which are subequal in length. Midlobe of mesoscutum with single adnotaular seta placed in posterior half. Anterior seta on scutellum longer than posterior one. Dorsellum very short (0.2–0.3× as long as broad). Propodeum well sculptured, with distinct median carina and anterior margin not covered by dorsellum. Forewing with distinct speculum and bare area behind marginal vein.

Female.—Length 0.9–1.3mm. Body mainly yellowish (Fig. 1); following parts brown to black: ocellar triangle, basal portion of pedicel (about half pedicel length), flagellar segments, mesosternum, metanotum, transverse band on 3–4th gastral segments. *Head* (Fig. 4): Frons with broad median area rather than distinct median line. Malar space about 0.5× eye height. Malar sulcus (Fig. 5) without fovea, distinctly curved especially beneath eye. Anterior margin of clypeus slightly bilobate, without distinct teeth. Mandible 3-dentate. *Antenna* (Fig. 14): Torulus placed slightly above lowest margin of eye. Scape 5.0–5.5× as long as wide, slightly longer than eye height, and reaching the top of vertex.

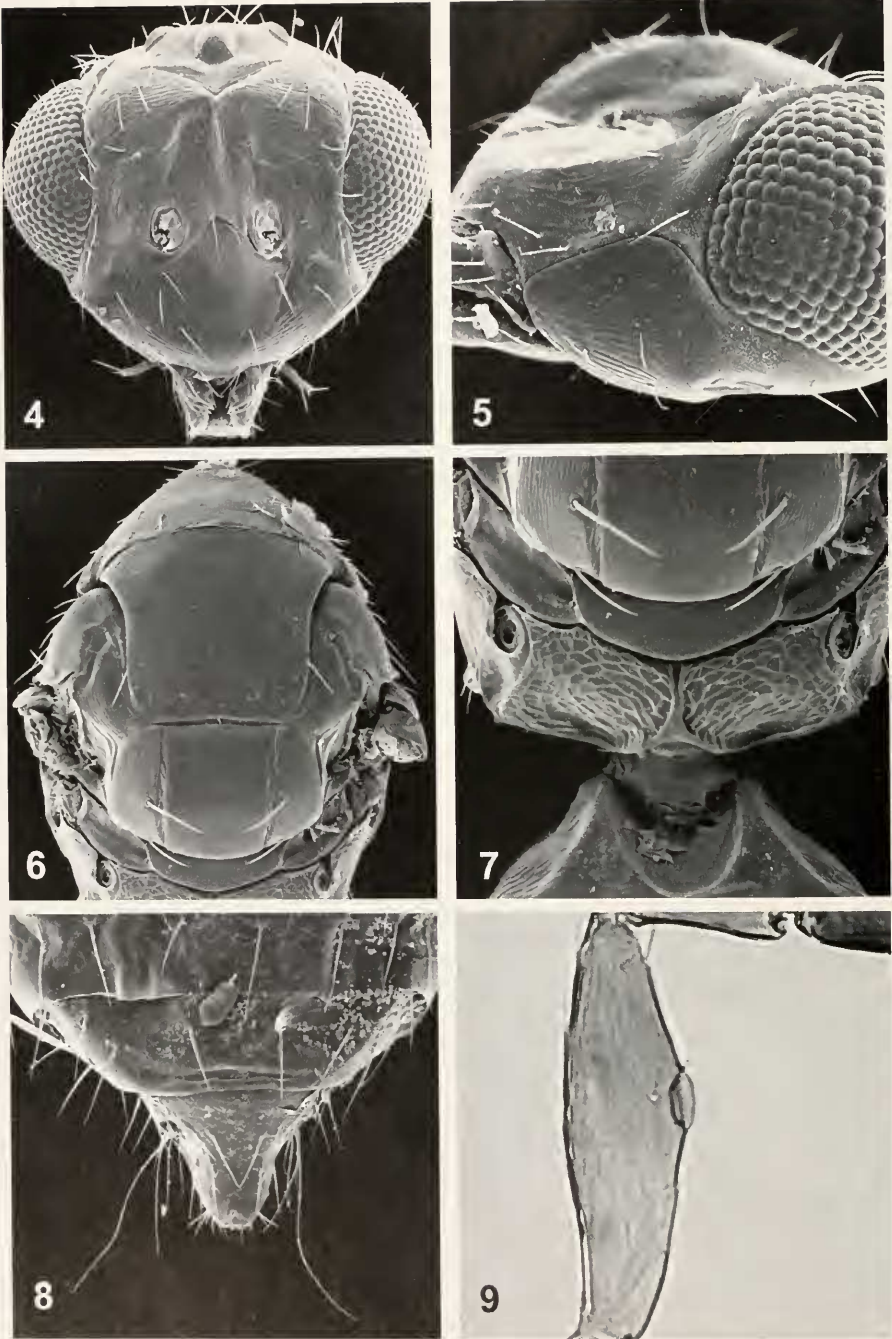
One anellus. First funicular segment slightly shorter than other two which are subequal in length (F1 about 0.7–0.8× as long as F2 or F3 length). Club 3-segmented, 5.0–5.5× as long as wide, slightly longer than F2 and F3 combined; distinct terminal spine and oblique suture between apical 2 segments. *Mesosoma* (Figs. 6–7): Slightly sculptured. Pronotum medially about 0.3× as long as mesoscutum. Midlobe of mesoscutum 1.5–1.6× longer than scutellum, with very weak to indistinct median line and single adnotaular seta placed in posterior half. Scutellum about 0.6× as long as broad. Dorsellum very short (0.2–0.3× as long as broad), not extending posteriorly over propodeum, 0.2–0.3× as long as scutellum. Propodeum more strongly sculptured than thorax and with distinct median carina and distinct paraspicular carina which encloses a concave area surrounding spiracle. *Fore wing* (Fig. 10): 2–2.2× as long as broad. Submarginal vein with a single dorsal seta. Marginal vein 6.2× longer than stigmal vein. Postmarginal vein present, about 0.9× as long as stigmal vein. Fringe on marginal vein 0.1–0.2× width of wing. Speculum present and extending below marginal vein for 0.2–0.3× its length; bare area extending behind full length of marginal vein. *Metasoma*: Ovate and slightly shorter than head and mesosoma combined. Cercus (Fig. 8) with one seta distinctly longer than the remaining setae and sinuate.

Pupa.—Yellow-orange with dark longitudinal stripe for entire length (Fig. 2). Meconium usually can be found outside the pupa near the caudal region.

Male.—Length 0.7–1.1mm. Similar to female except darker markings: pronotum, axilla partially and costula, mesosternum, mesopleura, mesoscutum especially in anterior half, propodeum, dorsellum and finally gaster in posterior half. *Fore wing*: Fringe distinct, setae on marginal vein about 0.3× width of wing (Fig. 11). *Antenna* (Fig. 15): Basal whorls of setae present



Figs. 1-3. 1-2, *Quadrastichus citrella*, female. 1, Ovipositing on *Phyllocnistis citrella* larva. 2, Pupa. 3, *Quadrastichus plaquoi*, female.



Figs. 4-9. 4-8, *Quadrastichus citrella*, female. 4, Head, frontal view. 5, Malar space. 6, Thorax. 7, Propodeum. 8, Cercal setae. 9, *Quadrastichus citrella*, male, scape.

on all funicular segments and at least $0.5\times$ as long as flagellum length. Funicle segments ratio F1/F2/F3/F4: 5/12/15/16. Club slightly longer than F1 and F2 combined. Ventral plaque (Fig. 9) on scape ovate, very small (about $0.1\text{--}0.2\times$ as long as scape), and placed about slightly above the middle.

Etymology.—This species is named for the specific name of its host, *Phyllocnistis citrella* Stainton.

Distribution.—*Quadrastichus citrella* is recorded as a native of China, Japan, Taiwan and Thailand (as *Q. sp. "A"* in Schauff et al. 1998).

Biology.—*Quadrastichus citrella* is an idiobiont ectoparasitoid of second and third *Phyllocnistis citrella* instar larvae, the only host recognized by now. Its developmental cycle takes about 20 days at 20°C and R.H. $>80\%$; at the same temperature, the adults survive up to 40 days (as *Q. sp.* in Argov and Rössler 1998, Llácer et al. 1998).

Type material.—Holotype ♀: Thailand, 1996, Y. Rössler, ex *Phyllocnistis citrella* Stainton (BMNH). Paratypes 22♂, 31♀, deposited as follows: same data as holotype (1♂, 5♀ ANIC; 1♂, 3♀ BMNH; 1♂, 5♀ DISTEF; 1♂, 3♀ EMBT; 1♂, 1♀ INPC; 1♀ IZCAS; 1♂, 2♀ USNM); Israel, Bet Dagan, Jaffa Corp., first delivery from Israel to Catania (Italy), 18.iv.1996, coll. by E. Swirski, ex *P. citrella* (2♂, 1♀ ANIC; 2♂, 1♀ DISTEF); Italy, University of Catania, mass rearing on *P. citrella*, 26.vi.1996, coll. by G. Siscaro (2♂, 2♀ ANIC; 2♂, 1♀ BMNH; 4♂, 3♀ DISTEF; 2♂, 1♀ EMBT; 1♂, 1♀ IZCAS; 1♂, 1♀ USNM).

Comments.—Several specimens (with the same data as the type material) have been examined and the only variation we could recognize is with the coloration on mesoscutum and gaster. The anterior half of midlobe of mesoscutum can sometimes have some brownish markings, while the transverse band on 3–4th gastral segments may rarely be either larger or indistinct.

Quadrastichus citrella may be distin-

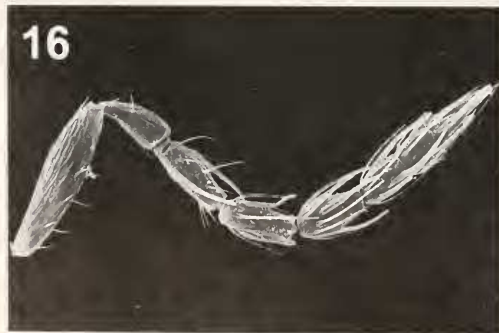
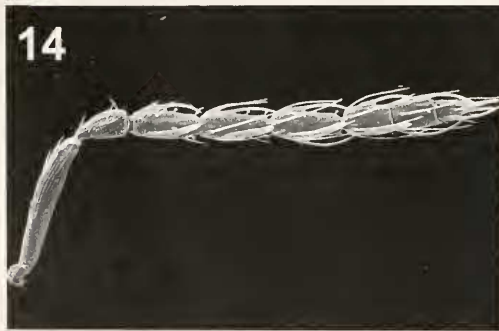
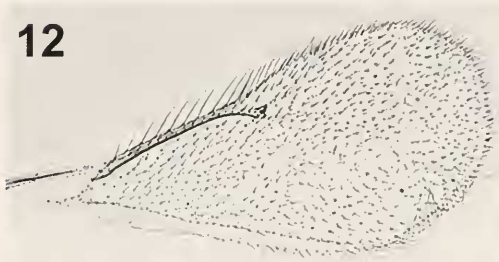
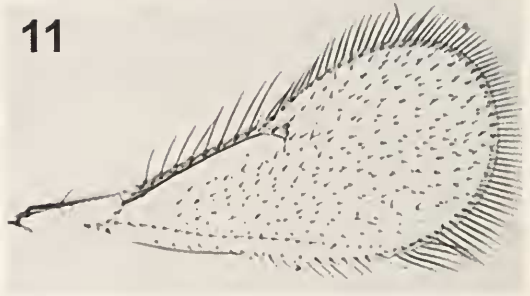
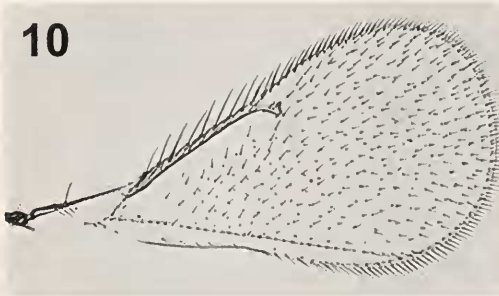
guished from both *Quadrastichus liriomyzae* Hansson and La Salle and *Q. plaquoi* by having dorsellum very short ($0.2\text{--}0.3\times$ as long as broad), fore wing with a distinct speculum (extending below marginal vein for $0.2\text{--}0.3\times$ its length) and the area behind marginal vein asetose for its entire length; males can also be recognized by having a distinctly smaller plaque on scape: it is oval in shape, about $0.1\text{--}0.2\times$ as long as scape length, and placed slightly above the middle. *Quadrastichus liriomyzae* and *Q. plaquoi* have a longer dorsellum (at least $0.4\times$ as long as broad), fore wings have speculum almost indistinct, the area behind marginal vein setose for its entire length, and males have also a longer ventral plaque on the scape: about 0.6 (*liriomyzae*) or 0.7 (*plaquoi*) \times as long as scape length.

Quadrastichus plaquoi Reina and La Salle, sp. nov.

(Figs. 3, 12, 13, 16–22)

Diagnosis.—Body yellowish with dark spot in middle of pronotum and with transverse dark band on 4th gastral segment. Frons with broad median area rather than distinct median line. Malar sulcus curved and without fovea beneath eye. Antennal scape reaching slightly higher than top of vertex. First and second funicular segments equal in length. Midlobe of mesoscutum with single adnotaular seta placed in posterior half. Anterior seta on scutellum longer than posterior one. Propodeum quite shiny, without a distinct median carina. Dorsellum rounded posteriorly, at least $4.0\times$ as long as broad. Forewing with speculum very small, area just distal to basal vein almost completely covered with setae, and area behind marginal vein setose.

Female.—Length 0.9–1.4mm. Body mainly yellowish (Fig. 3) with following parts brown to black: basal portion of pedicel (about 0.5 its length), ocellar triangle, flagellar segments, medial 0.3–0.4 of pronotum, mesoscutum anteriorly, median



Figs. 10-17. 10, 11, 14, 15, *Quadrastichus citrella*. 10, Female fore wing. 11, Male fore wing. 14, Female antenna. 15, Male antenna. 12, 13, 16, 17, *Quadrastichus plaquoi*. 12, Female fore wing. 13, Male fore wing. 16, Female antenna. 17, Male antenna.

area on the propodeum, and transversal band on 4th gastral segment. *Head* (Fig. 18): Frons without a distinct median line and with only broad median area. Malar space about $0.6\times$ as long as eye height. Malar sulcus (Fig. 19) distinctly curved and without fovea. Clypeus truncate anteriorly, without distinct teeth. Mandible 3-dentate. *Antenna* (Fig. 16): Torulus placed slightly above lowest eye margin. Scape $5\times$ as long as wide, reaching slightly above top of vertex. One anellus present. First and second funicular segments equal in length, third one about $0.8\times$ as long as other two. Club 3-segmented, $4.0\text{--}4.5\times$ as long as wide, longer than F1 and F2 combined, with distinct terminal spine and suture between apical 2 segments slightly oblique. *Mesosoma* (Figs. 20, 21): Pronotum uniformly lineolate, medially $0.2\text{--}0.3\times$ as long as mesoscutum. Midlobe of mesoscutum slightly sculptured, $1.6\text{--}1.7\times$ longer than scutellum, and with a very weak to indistinct median line; single adnotaular seta present in posterior half. Scutellum about $0.7\times$ as long as broad. Dorsellum at least $0.4\times$ as long as broad, evenly rounded posteriorly, $0.3\text{--}0.4\times$ as long as scutellum and slightly extending posteriorly over propodeum. Propodeum shiny and without distinct median carina; distinct paraspicular carina present which encloses a concave area associated with spiracle. *Fore wing* (Fig. 12): $2.2\text{--}2.4\times$ as long as broad. Submarginal vein with single dorsal seta. Marginal vein about $4\times$ as long as stigmal vein. Postmarginal vein slightly shorter than stigmal vein: about $0.9\times$ as long as stigmal vein. Fringe on marginal vein $0.2\text{--}0.3\times$ as long as wing width. Speculum very small, area just distal to basal vein almost completely covered with setae, and area behind marginal vein setose. *Metasoma*: Oval in shape in dorsal view and slightly shorter than head and mesosoma together. Cercus with one seta distinctly longer than remaining setae and sinuate. Tip of ovipositor slightly exerted.

Male.—Length $0.7\text{--}0.9\text{mm}$. Similar to fe-

male but with darker markings as follows: anterior half of mesoscutum, metanotum, dorsellum, propodeum and almost entire basal half of gaster. *Fore wing* with fringe distinct, and setae on marginal vein about $0.3\times$ width of wing (Fig. 13). *Antenna* (Fig. 17): Basal whorls of setae present on all the funicular segments and about $0.4\text{--}0.5\times$ as long as flagellum length. Funicular segments ratio F1/F2/F3/F4: $6/10/11/9$. Club longer than F2 and F3 combined, which are longest funicular segments. Ventral plaque (Fig. 22) on scape placed medially and large: about $0.7\times$ long as scape length.

Etymology.—Males of this species have a large ventral plaque on the scape in comparison with the much smaller one present in *Q. citrella*; therefore, the name *plaqoui* refers to this character.

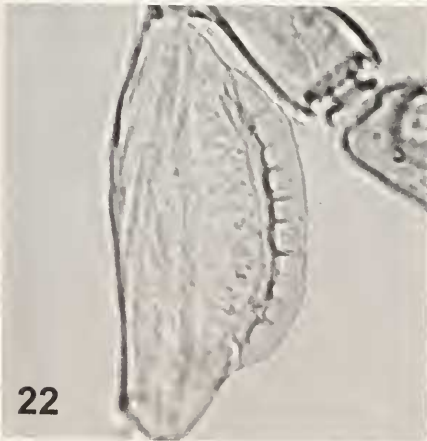
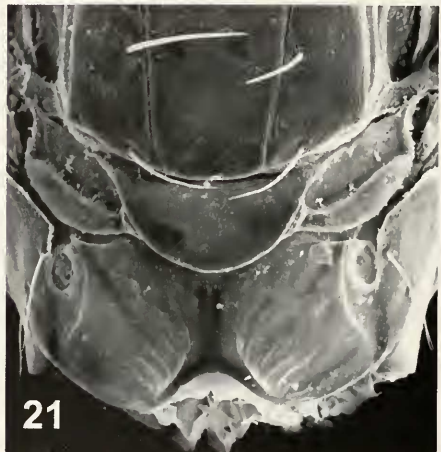
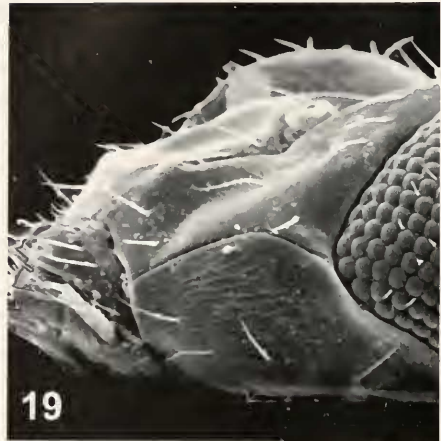
Distribution.—Known only from Himachal Pradesh, India.

Biology.—*Quadrastichus plaqoui* has been recorded only on *Liriomyza trifolii* (Burgess).

Type material.—Holotype ♀: India, Sulam, Himachal Pradesh, 2000, ex *Liriomyza trifolii* (Burgess) (BMNH). Paratypes 5δ , 9η , deposited as follows: data as holotype (1δ , 3η ANIC; 1δ , 1η BMNH, 2η DISTEF; 1δ , 1η INPC; 1δ , 1η IZCAS; 1δ , 1η USNM).

Comments.—No distinguishable variation has been recognized from the examined material.

It may be difficult to distinguish *Q. plaqoui* from *Q. liriomyzae*. The *Q. plaqoui* female has F1 and F2 equal in length and scape reaching slightly above the apex of vertex; moreover, both sexes have pronotum mainly yellow with a median dark area. *Q. liriomyzae* female has F1 slightly shorter than F2, scape not reaching above the apex of vertex and both sexes have pronotum dorsally entirely dark. *Q. plaqoui* can be distinguished from *Q. citrella* as suggested above in *Q. citrella* description, and in the key below.



Figs. 18–22. 18–21, *Quadrastichus plaquoi*, female. 18, Head, frontal view. 19, Malar space. 20, Thorax. 21, Propodeum. 22, *Quadrastichus plaquoi*, male, scape.

DISCUSSION

Within the genus, *Q. citrella* and *Q. plaquoi* belong to the "anysis group" (see Graham 1991), with which they share extensive yellow markings on the body, frons usually with a median area rather than a median carina, malar sulcus curved and

not foveate, pronotum uniformly sculptured and scutellum without an offset strip along its hind edge. Other species within this group are the European *Q. citrinus* (Thomson) and *Q. xanthosoma* (Graham), the North American *Q. flora* (Girault) and the Asian *Q. liriomyzae* Hansson and La Salle.

KEY TO OLD WORLD SPECIES OF THE "ANYSIS GROUP" OF *QUADRASTICHUS*

1. Both sexes: mesoscutum completely dark brown to black; speculum distinct and extending almost half of marginal vein length. Male: ventral plaque about $0.5 \times$ scape length *Q. anysis* (Walker)
 - Both sexes: mesoscutum partially to totally yellowish. Other characters variable 2
2. Female: $F1 \geq 1.3 \times F2$ 3
 - Female: $F1 \leq F2$ 4
3. Female: gaster $1.5 \times$ longer than hind tibia; thorax and gaster mainly blackish; last tergite $0.8-1.5 \times$ as long as broad (see Graham 1974, 1991) *Q. citrinus* (Thomson)
 - Female: gaster $2.0 \times$ longer than hind tibia; thorax and gaster mainly yellow; last tergite $1.3-2.0 \times$ as long as broad (see Graham 1974, 1991) *Q. xanthosoma* (Graham)
4. Both sexes: pronotum mainly yellow with a dark spot medially. Female: $F1 = F2$. Male: ventral plaque (Fig. 22) placed medially and about $0.7 \times$ long as scape length *Q. plaquoi*, n. sp.
 - Female: $F1 < F2$; pronotum different, either entirely dark dorsally (*liriomyzae*) or entirely yellow (*citrella*). Male: pronotum entirely dark; ventral plaque on scape variable 5
5. Both sexes: speculum indistinct, area just distal to basal vein almost completely setose; area behind marginal vein setose for entire its length. Female: pronotum dark dorsally. Male: ventral plaque on scape about $0.6 \times$ as long as scape length *Q. liriomyzae* Hansson and La Salle
 - Both sexes: speculum present and extending below marginal vein for $0.2-0.3 \times$ its length; area behind marginal vein a setose for entire its length. Female: pronotum yellow dorsally. Male: ventral plaque (Fig. 9) about $0.1-0.2 \times$ as long as scape length *Q. citrella*, n. sp.

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